Fig. 1
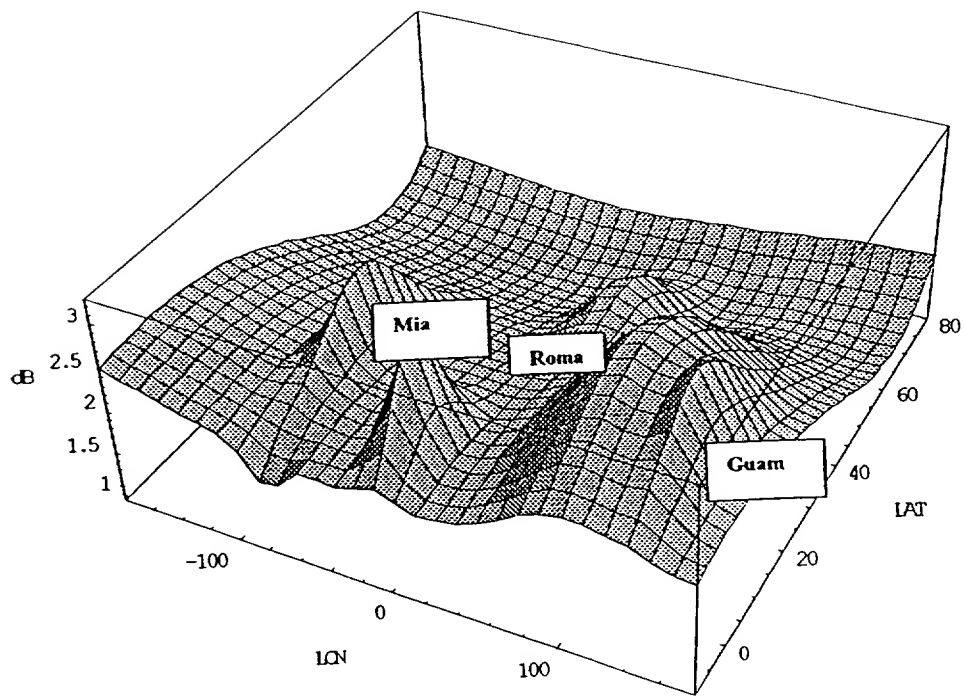
Fig. 2
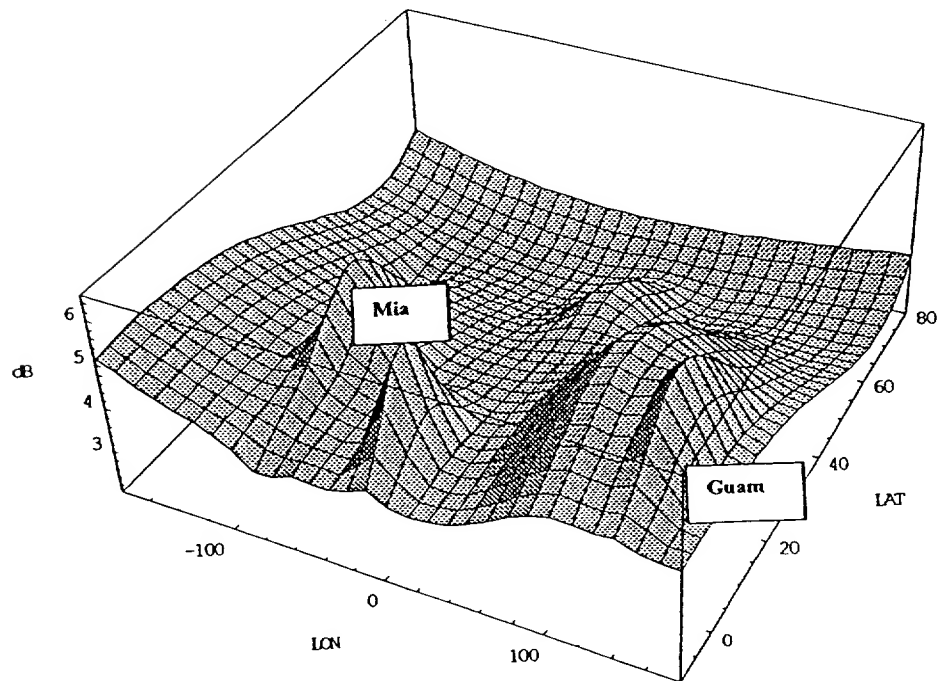

Fig. 3

Short Form Global Equation for Non Rainy Zenith Attenuation (dB) For the 6-100 GHz Region; fg=Frequency, GHz

LIEBE azen=

$$0.000408122\,\text{fg}^2\left(5.34566 + 1.48098E^{-\frac{1}{200}(10+LAT)^2-\frac{1}{200}(-145+LON)^2} + 2.03295E^{-\frac{1}{800}(-18+LAT)^2-\frac{(102+LON)^2}{1800}} + \right.$$

$$1.1968E^{-\frac{1}{200}(-52+LAT)^2-\frac{1}{800}(-28+LON)^2} - 2.78685E^{-\frac{LAT^2}{1800}-\frac{LON^2}{180000}} + 2.48024E^{-\frac{1}{72}(-2+LAT)^2-\frac{1}{200}(7+LON)^2} +$$

$$1.41803E^{-\frac{1}{50}(-20+LAT)^2-\frac{1}{200}(60+LON)^2} - 2.26449E^{-\frac{1}{200}(28+LAT)^2-\frac{1}{200}(77+LON)^2} +$$

$$1.69839E^{-\frac{1}{200}(-20+LAT)^2-\frac{1}{128}(82+LON)^2} + 0.000898808\ LAT - 0.00187405\ LAT^2 + 8.15535\times10^{-7}\ LAT^3 +$$

$$1.92203\times10^{-7}\ LAT^4 - 0.000690105\ LON - 5.83206\times10^{-6}\ LAT\ LON + 3.42574\times10^{-7}\ LAT^2\ LON +$$

$$\left.0.0000243378\ LON^2 + 1.15354\times10^{-8}\ LATLON^2 - 3.5046\times10^{-8}\ LON^3 - 6.44437\times10^{-11}\ LON^4\right) +$$

$$0.00586939\ \text{fg}^2\left(3.14686 + 0.665394E^{-\frac{1}{200}(-10+LAT)^2-\frac{1}{200}(-145+LON)^2} + \right.$$

$$1.1188E^{-\frac{1}{800}(-18+LAT)^2-\frac{(-102+LON)^2}{1800}} + 0.716478E^{-\frac{1}{200}(52+LAT)^2-\frac{1}{800}(-28+LON)^2} +$$

$$1.18012E^{-\frac{LAT^2}{1800}-\frac{LON^2}{180000}} + 1.21591E^{-\frac{1}{72}(-2+LAT)^2-\frac{1}{200}(7+LON)^2} - 1.89544E^{-\frac{1}{200}(28+LAT)^2-\frac{1}{200}(77+LON)^2} +$$

$$0.8941E^{-\frac{1}{200}(-20+LAT)^2-\frac{1}{128}(82+LON)^2} + 0.00101461\ LAT - 0.000943554\ LAT^2 + 2.75301\times10^{-7}\ LAT^3 +$$

$$1.00142\times10^{-7}\ LAT^4 - 0.000268921\ LON - 1.63982\times10^{-6}\ LATLON + 2.33496\times10^{-7}\ LAT^2\ LON +$$

$$0.0000108872\ LON^2 + 1.02349\times10^{-8}\ LATLON^2 - 1.77808\times10^{-8}\ LON^3 - 1.11299\times10^{-10}\ LON^4 -$$

$$0.201139\left(5.34566 + 1.48098E^{-\frac{1}{200}(10+LAT)^2-\frac{1}{200}(-145+LON)^2} + 2.03295E^{-\frac{1}{800}(-18+LAT)^2-\frac{(-102+LON)^2}{1800}} + \right.$$

$$1.1968E^{-\frac{1}{200}(-52+LAT)^2-\frac{1}{800}(-28+LON)^2} - 2.78685E^{-\frac{LAT^2}{1800}-\frac{LON^2}{180000}} + 2.48024E^{-\frac{1}{72}(-2+LAT)^2-\frac{1}{200}(7+LON)^2} +$$

$$1.41803E^{-\frac{1}{50}(-20+LAT)^2-\frac{1}{200}(60+LON)^2} - 2.26449E^{-\frac{1}{200}(28+LAT)^2-\frac{1}{200}(77+LON)^2} +$$

$$1.69839E^{-\frac{1}{200}(-20+LAT)^2-\frac{1}{128}(82+LON)^2} + 0.000898808\ LAT - 0.00187405\ LAT^2 + 8.15535\times10^{-7}\ LAT^3 +$$

$$1.92203\times10^{-7}\ LAT^4 - 0.000690105\ LON - 5.83206\times10^{-6}\ LAT\ LON + 3.42574\times10^{-7}\ LAT^2\ LON +$$

$$\left.\left.0.0000243378\ LON^2 + 1.15354\times10^{-8}\ LATLON^2 - 3.5046\times10^{-8}\ LON^3 - 6.44437\times10^{-11}\ LON^4\right)\right)$$

$$\left(0.665418 - 132.118\left(-0.740741 + 0.0333667\ \text{fg}\right)^2\right.$$

$$\left(0.999375 - 11.4943\ \sqrt{(-0.740741 + 0.0333667\ \text{fg})^2}\ ArcTan\left[\sqrt{\frac{0.0869456}{(-0.740741 + 0.0333667\ \text{fg})^2}}\right]\right) -$$

$$132.118\left(0.740741 + 0.0333667\ \text{fg}\right)^2$$

$$\left.\left(0.999375 - 11.4943\sqrt{(0.740741 + 0.0333667\ \text{fg})^2}\ ArcTan\left[\sqrt{\frac{0.0869456}{(0.740741 + 0.0333667\ \text{fg})^2}}\right]\right)\right) -$$

$$0.00392386\ \text{fg}^2\left(18.2482\left(Log\left[\frac{(2 - 0.0333667\ \text{fg})^2}{0.000749822 + (2 - 0.0333667\ \text{fg})^2}\right] + \right.\right.$$

$$Log\left[\frac{(3.9999999999999 - 0.0333667\ \text{fg})^2}{0.000187456 + (3.9999999999999 - 0.0333667\ \text{fg})^2}\right] +$$

$$Log\left[\frac{(\frac{61}{10} - 0.0333667\ \text{fg})^2}{0.000187456 + (\frac{61}{10} - 0.0333667\ \text{fg})^2}\right] + Log\left[\frac{(2 + 0.0333667\ \text{fg})^2}{0.000749822 + (2 + 0.0333667\ \text{fg})^2}\right] +$$

$$Log\left[\frac{(3.9999999999999 + 0.0333667\ \text{fg})^2}{0.000187456 + (3.9999999999999 + 0.0333667\ \text{fg})^2}\right] +$$

$$\left.Log\left[\frac{(\frac{61}{10} + 0.0333667\ \text{fg})^2}{0.000187456 + (\frac{61}{10} + 0.0333667\ \text{fg})^2}\right]\right) +$$

$$\left.27.7778\ Log\left[\frac{0.00111334\ \text{fg}^2}{0.00032359 + 0.00111334\ \text{fg}^2}\right]\right)$$

Fig. 4

Fig. 5

Fig. 6

$$
-1158.02
$$

$$
\left(1. + \left(-0.139753\left(\left(-0.139753\Big(1.79394\times10^{-7}\,LAT + 8.75845\times10^{-7}\,LAT^3 + 3.25314\times10^{-7}\,LONLAT^2 - 0.00176137\,LAT^2 + 3.07508\times10^{-9}\,LON^2LAT - 6.69472\times10^{-6}\,LONLAT + 0.000919687\right.\right.\right.\right.
$$

$$
LAT + 1.49573\,e^{-\frac{1}{200}(LAT-10)^2 - \frac{1}{200}(LON-145)^2} + 2.04653\,e^{-\frac{1}{800}(LAT-18)^2 - \frac{(LON-102)^2}{1800}} + 1.16178\,e^{-\frac{1}{200}(LAT-52)^2 - \frac{1}{800}(LON-28)^2} - 2.25769\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} - 2.51927\,e^{-\frac{LAT^2}{1800} - \frac{LON^2}{180000}} +
$$

$$
2.46395\,e^{-\frac{1}{72}(LAT-2)^2 - \frac{1}{200}(LON-7)^2} + 1.41489\,e^{-\frac{1}{50}(LAT-20)^2 - \frac{1}{200}(LON-60)^2} - 2.25769\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} + 1.69814\,e^{-\frac{1}{200}(LAT-20)^2 - \frac{1}{128}(LON-82)^2} -
$$

$$
1.07578\,e^{-\frac{1}{98}(LAT-45)^2 - \frac{1}{128}(LON-110)^2} - 4.24764\times10^{-11}\,LON^3 - 3.34843\times10^{-8}\,LON^2 + 0.0000241438\,LON^2 - 0.000725197\,LON + 3.84195\Big)
$$

$$
\frac{1}{(293.-0.25\,(LAT-40.))^2}\left(85849.\left(0.139753\Big(1.79394\times10^{-7}\,LAT + 8.75845\times10^{-7}\,LAT^3 + 3.25314\times10^{-7}\,LONLAT^2 - 0.00176137\,LAT^2 + \right.\right.
$$

$$
3.07508\times10^{-9}\,LON^2LAT - 6.69472\times10^{-6}\,LONLAT + 0.000919687\,LAT + 1.49573\,e^{-\frac{1}{200}(LAT-10)^2 - \frac{1}{200}(LON-145)^2} +
$$

$$
2.04653\,e^{-\frac{1}{800}(LAT-18)^2 - \frac{(LON-102)^2}{1800}} + 1.16178\,e^{-\frac{1}{200}(LAT-52)^2 - \frac{1}{800}(LON-28)^2} - 2.51927\,e^{-\frac{LAT^2}{1800} - \frac{LON^2}{180000}} + 2.46395\,e^{-\frac{1}{72}(LAT-2)^2 - \frac{1}{200}(LON-7)^2} +
$$

$$
1.41489\,e^{-\frac{1}{50}(LAT-20)^2 - \frac{1}{200}(LON-60)^2} - 2.25769\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} + 1.69814\,e^{-\frac{1}{200}(LAT-20)^2 - \frac{1}{128}(LON-82)^2} -
$$

$$
1.07578\,e^{-\frac{1}{98}(LAT-45)^2 - \frac{1}{128}(LON-110)^2} - 4.24764\times10^{-11}\,LON^3 - 3.34843\times10^{-8}\,LON^2 + 0.0000241438\,LON^2 - 0.000725197\,LON + 3.84195\Big) + 1.01966\Big)\right)\right) +
$$

$$
\left(0.186801\Big(1.79394\times10^{-7}\,LAT + 8.75845\times10^{-7}\,LAT^3 + 3.25314\times10^{-7}\,LONLAT^2 - 0.00176137\,LAT^2 + 3.07508\times10^{-9}\,LON^2LAT -\right.
$$

$$
6.69472\times10^{-6}\,LONLAT + 0.000919687\,LAT + 1.49573\,e^{-\frac{1}{200}(LAT-10)^2 - \frac{1}{200}(LON-145)^2} + 2.04653\,e^{-\frac{1}{800}(LAT-18)^2 - \frac{(LON-102)^2}{1800}} +
$$

$$
1.16178\,e^{-\frac{1}{200}(LAT-52)^2 - \frac{1}{800}(LON-28)^2} - 2.51927\,e^{-\frac{LAT^2}{1800} - \frac{LON^2}{180000}} + 2.46395\,e^{-\frac{1}{72}(LAT-2)^2 - \frac{1}{200}(LON-7)^2} + 1.41489\,e^{-\frac{1}{50}(LAT-20)^2 - \frac{1}{200}(LON-60)^2} -
$$

$$
2.25769\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} + 1.69814\,e^{-\frac{1}{200}(LAT-20)^2 - \frac{1}{128}(LON-82)^2} - 1.07578\,e^{-\frac{1}{98}(LAT-45)^2 - \frac{1}{128}(LON-110)^2} -
$$

$$
4.24764\times10^{-11}\,LON^3 - 3.34843\times10^{-8}\,LON^2 + 0.0000241438\,LON^2 - 0.000725197\,LON + 3.84195\Big)\,\log(PR) - 0.919661\Big) +
$$

$$
\left(0.764706\Big(-0.352549\Big(1.03045\times10^{-7}\,LAT^4 + 2.23192\times10^{-7}\,LAT^2 + 2.44557\times10^{-7}\,LONLAT^2 - 0.0009754177\,LAT^2 - 0.0009754177\,LAT^2 + 1.0003\times10^{-8}\,LON^2\,LAT - 2.18586\times10^{-6}\,LONLAT +\right.\right.
$$

$$
0.00128521\,LAT + 0.66746\,e^{-\frac{1}{200}(LAT-10)^2 - \frac{1}{200}(LON-145)^2} + 1.12036\,e^{-\frac{1}{800}(LAT-18)^2 - \frac{(LON-102)^2}{1800}} + 0.70296\,e^{-\frac{1}{200}(LAT-52)^2 - \frac{1}{800}(LON-28)^2} -
$$

$$
1.28258\,e^{-\frac{LAT^2}{1800} - \frac{LON^2}{180000}} + 1.22726\,e^{-\frac{1}{72}(LAT-2)^2 - \frac{1}{200}(LON-7)^2} - 1.92779\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} + 0.865964\,e^{-\frac{1}{200}(LAT-20)^2 - \frac{1}{128}(LON-82)^2} -
$$

$$
0.0909198\,e^{-\frac{1}{98}(LAT-45)^2 - \frac{1}{128}(LON-110)^2} - 1.36816\times10^{-10}\,LON^3 - 1.38211\times10^{-8}\,LON^2 + 0.00001497\,LON^2 - 0.000416968\,LON + 2.53967\Big)\,\log(PR) + 0.332309\Big) +
$$

$$
\left(0.140592\Big(1.03045\times10^{-7}\,LAT^4 + 2.23192\times10^{-7}\,LAT^2 + 2.44557\times10^{-7}\,LONLAT^2 - 0.0009754177\,LAT^2 + 1.0003\times10^{-8}\,LON^2\,LAT -\right.
$$

$$
2.18586\times10^{-6}\,LONLAT + 0.00128521\,LAT + 0.66746\,e^{-\frac{1}{200}(LAT-10)^2 - \frac{1}{200}(LON-145)^2} + 1.12036\,e^{-\frac{1}{800}(LAT-18)^2 - \frac{(LON-102)^2}{1800}} +
$$

$$
0.70296\,e^{-\frac{1}{200}(LAT-52)^2 - \frac{1}{800}(LON-28)^2} - 1.28258\,e^{-\frac{LAT^2}{1800} - \frac{LON^2}{180000}} + 1.22726\,e^{-\frac{1}{72}(LAT-2)^2 - \frac{1}{200}(LON-7)^2} -
$$

$$
1.92779\,e^{-\frac{1}{200}(LAT-28)^2 - \frac{1}{200}(LON-77)^2} + 0.865964\,e^{-\frac{1}{200}(LAT-20)^2 - \frac{1}{128}(LON-82)^2} - 0.0909198\,e^{-\frac{1}{98}(LAT-45)^2 - \frac{1}{128}(LON-110)^2} +
$$

$$
1.36816\times10^{-10}\,LON^3 - 1.38211\times10^{-8}\,LON^2 + 0.00001497\,LON^2 - 0.000416968\,LON + 2.53967\Big) + 0.132924\Big)\,\log(PR) - 0.0878644\Big)\right)\right)\right)\right)
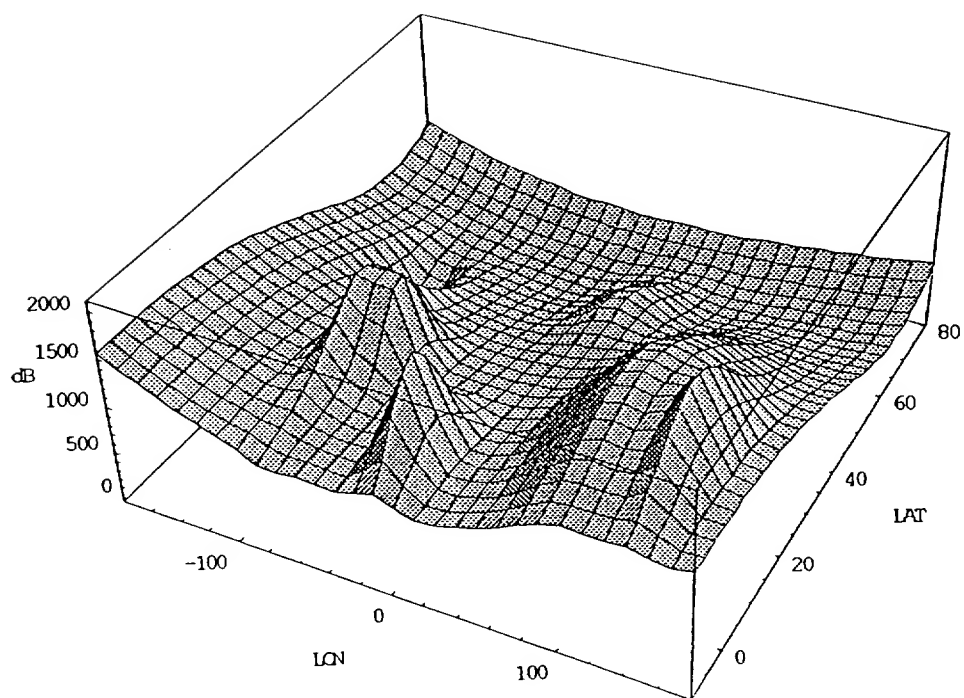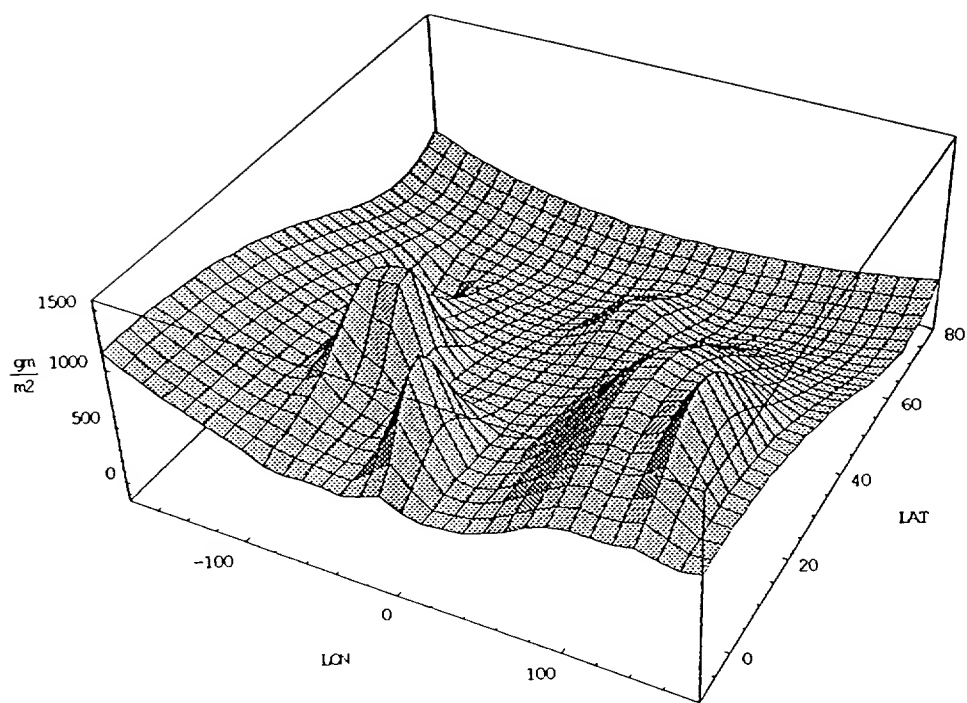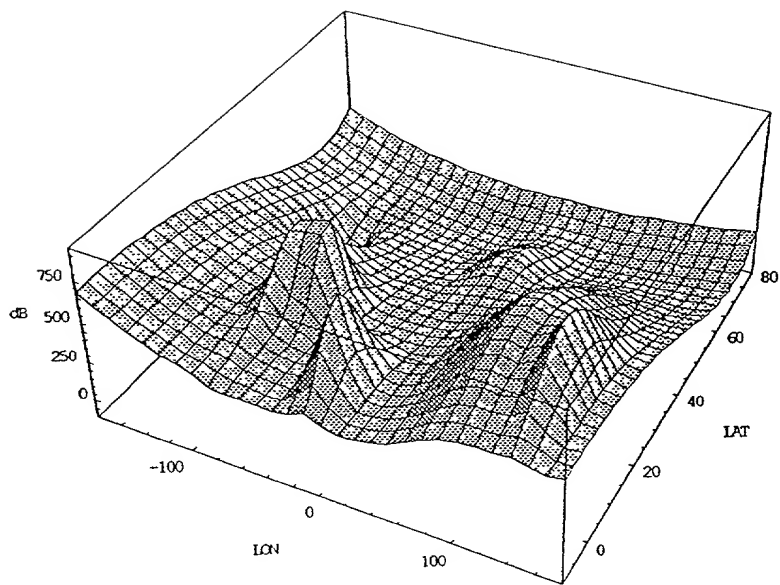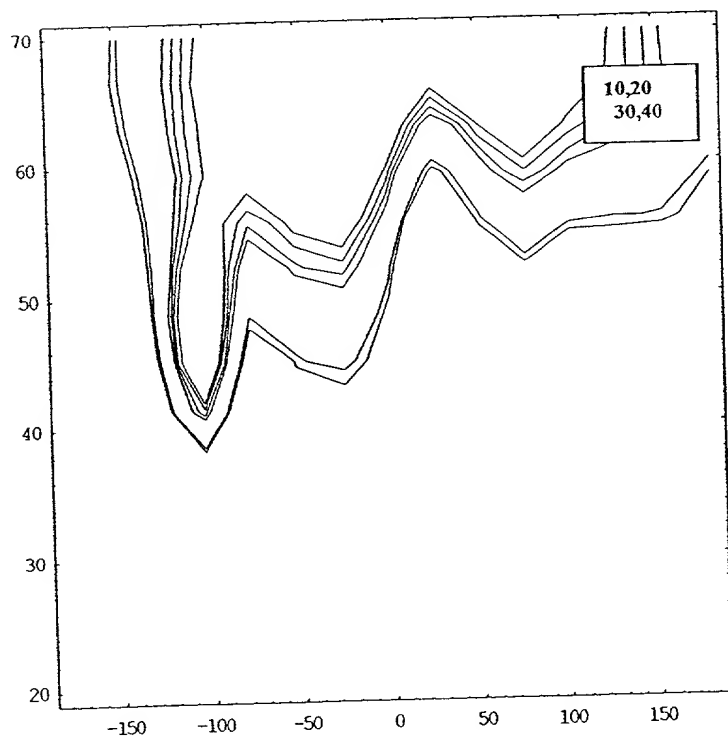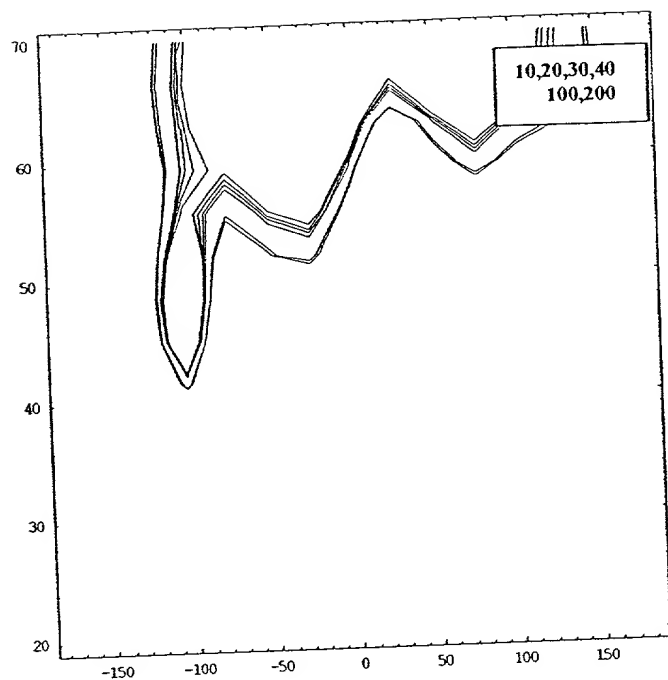$$

Fig. 7
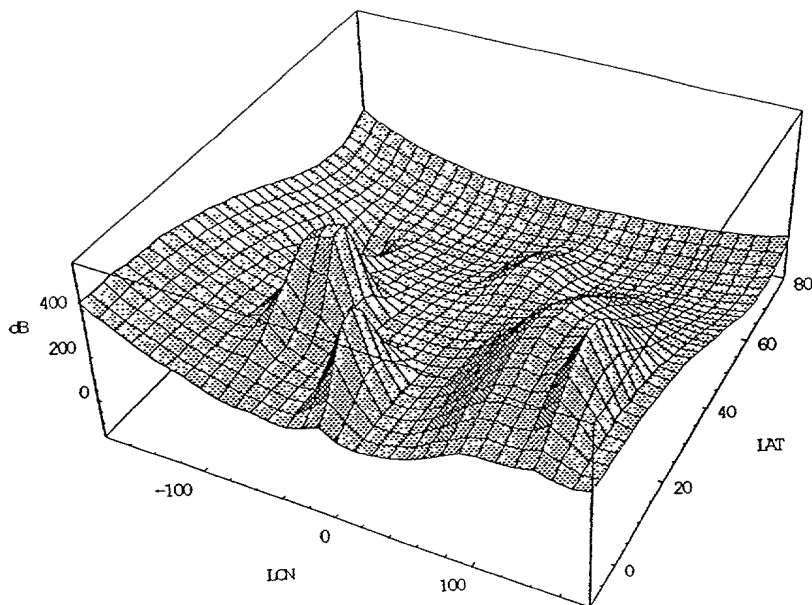
Fig. 8

Fig. 9
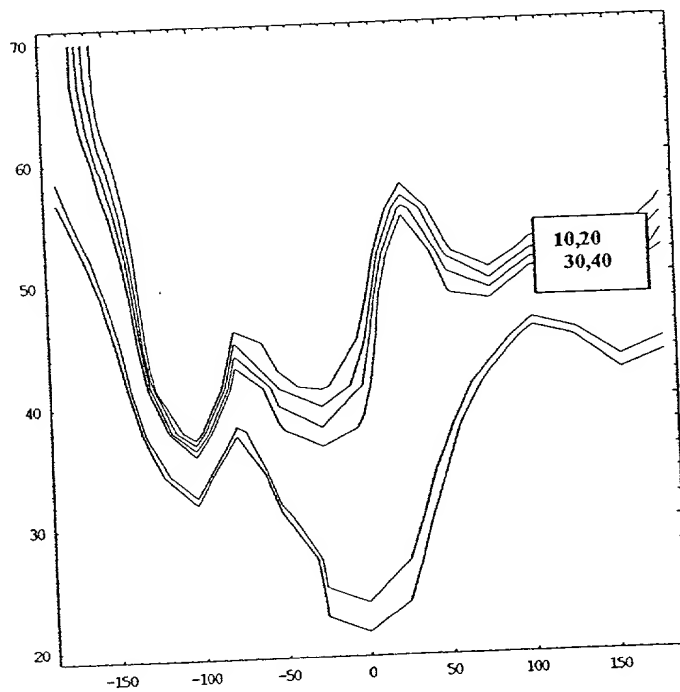
Fig. 10

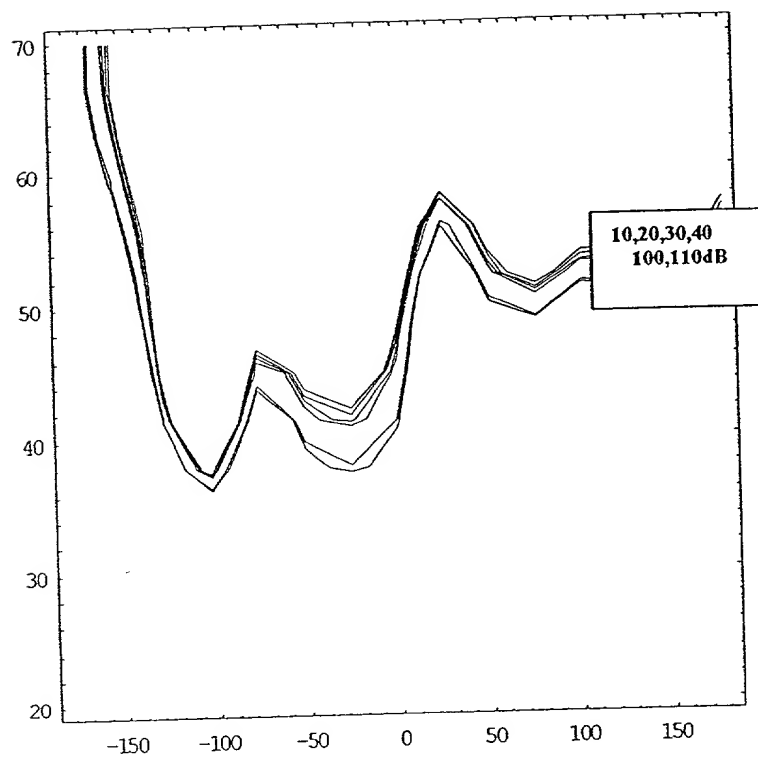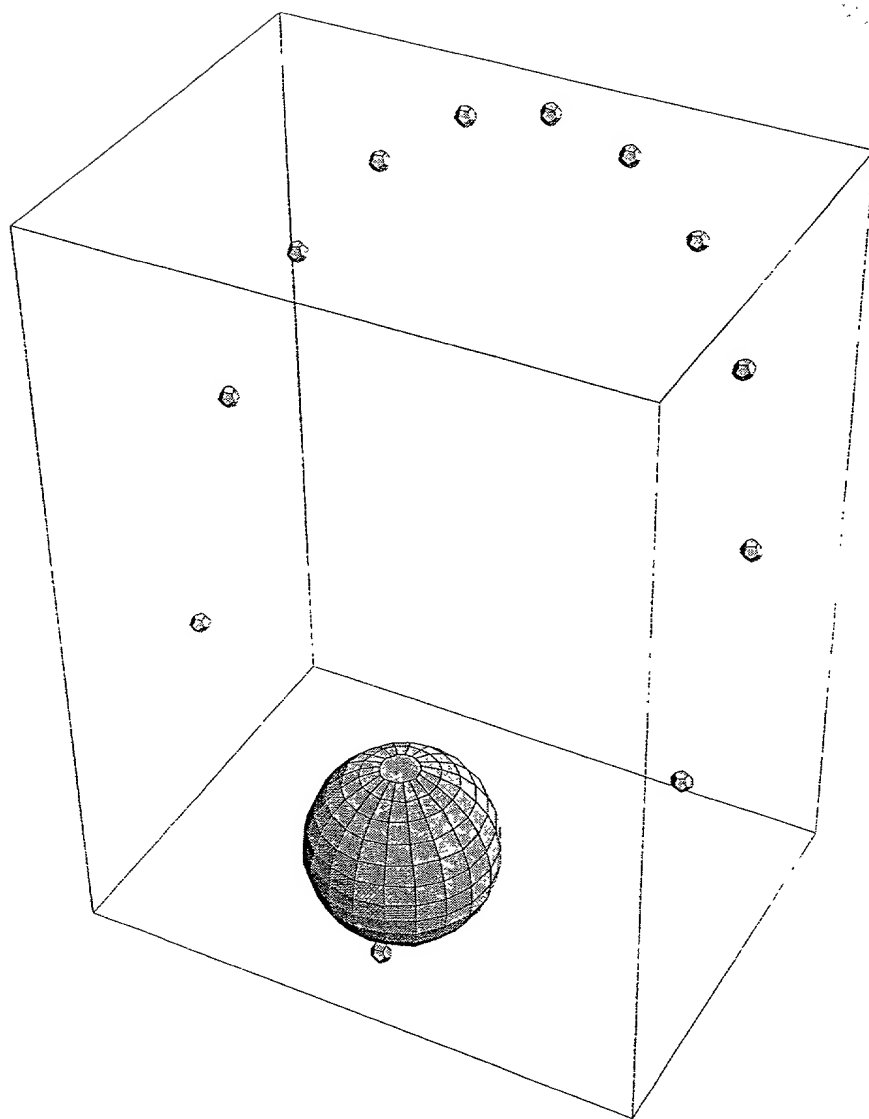Fig. 11

Fig. 12
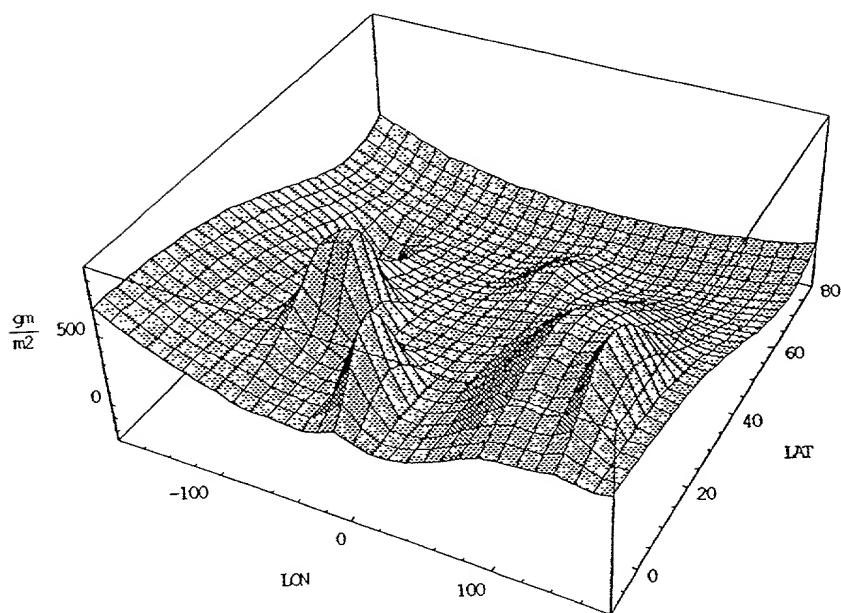
Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Molniya seen from Ground Station

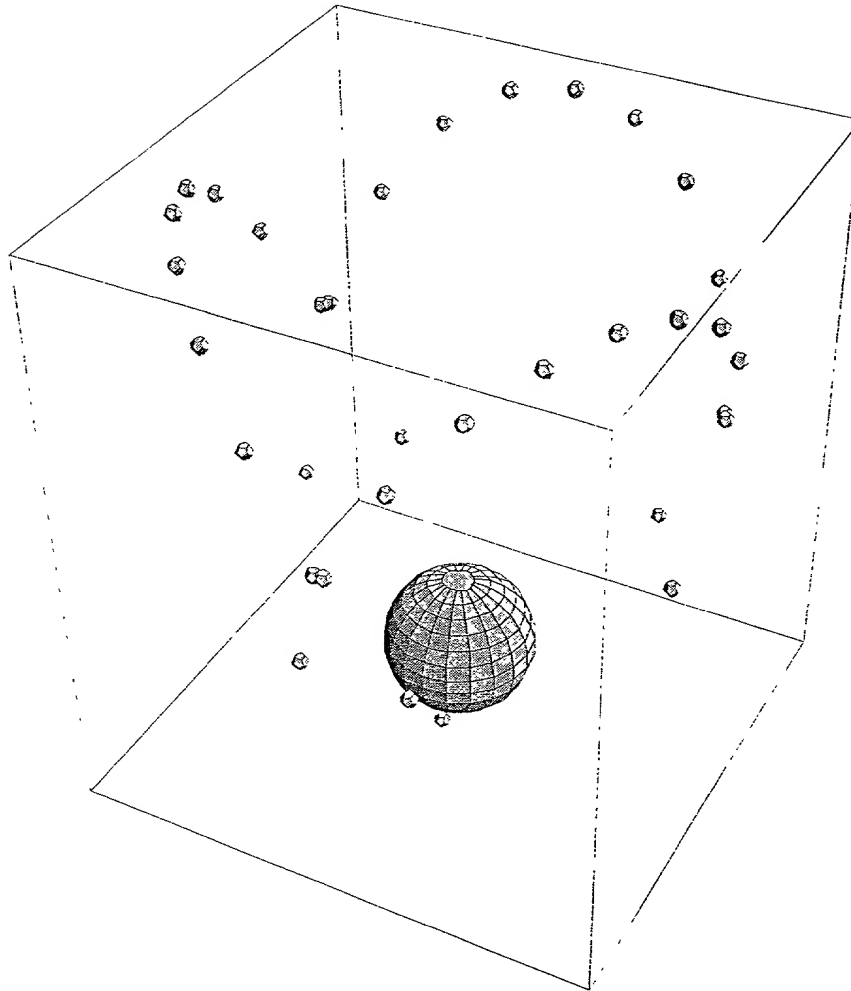

Fig. 18

MolniyaGEO pdf=

$$\frac{e^{-\dfrac{\left(5.22822 \times 10^{-6}\,LAT^4 - 0.000520006\,LAT^3 + 0.00512491\,LAT^2 + 0.165865\,LAT + x - 47.0509\right)^2}{2\left(0.00002 92 38\,LAT^4 - 0.00526509\,LAT^3 + 0.270942\,LAT^2 - 0.776901\,LAT + 181.722\,e^{-\frac{LAT^2}{900}} - 160.041\right)^2}}}{\left(0.00002 92 38\,LAT^4 - 0.00526509\,LAT^3 + 0.270942\,LAT^2 - 0.776901\,LAT + 181.722\,e^{-\frac{LAT^2}{900}} - 160.041\right)\sqrt{2\pi}}$$
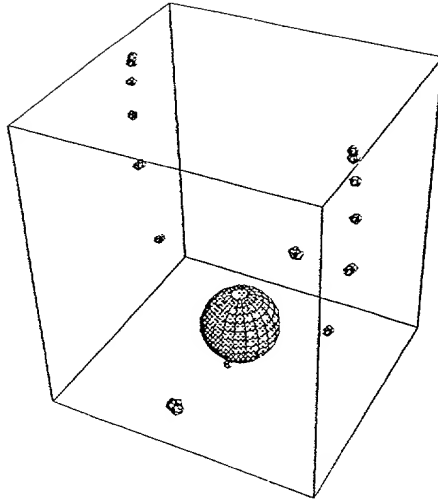
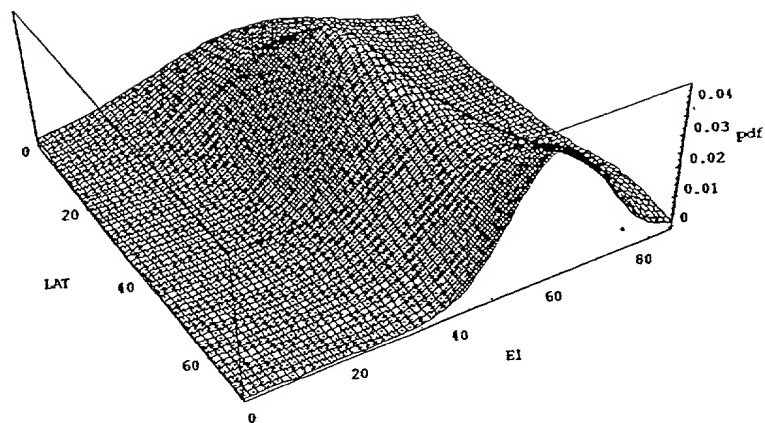With x representing elevation angle in degrees.

Fig. 19

Fig. 20

Fig. 21

Fig. 22

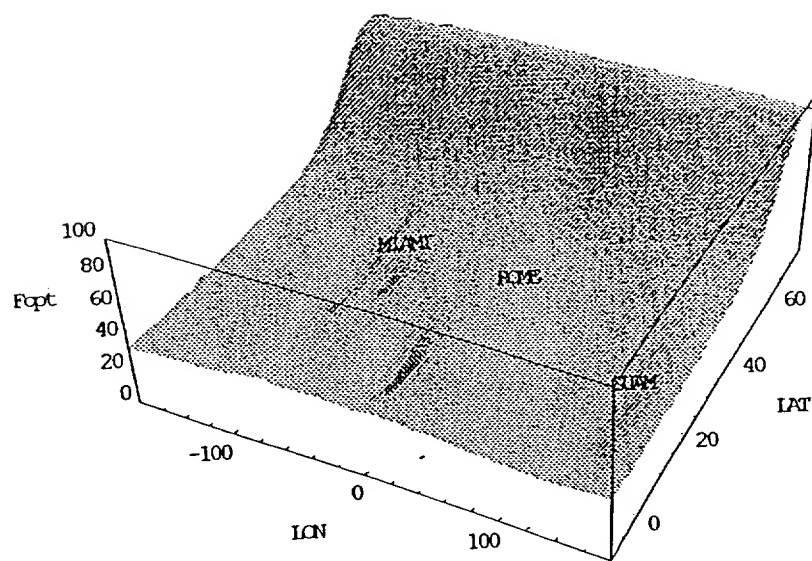Molniya Satellite
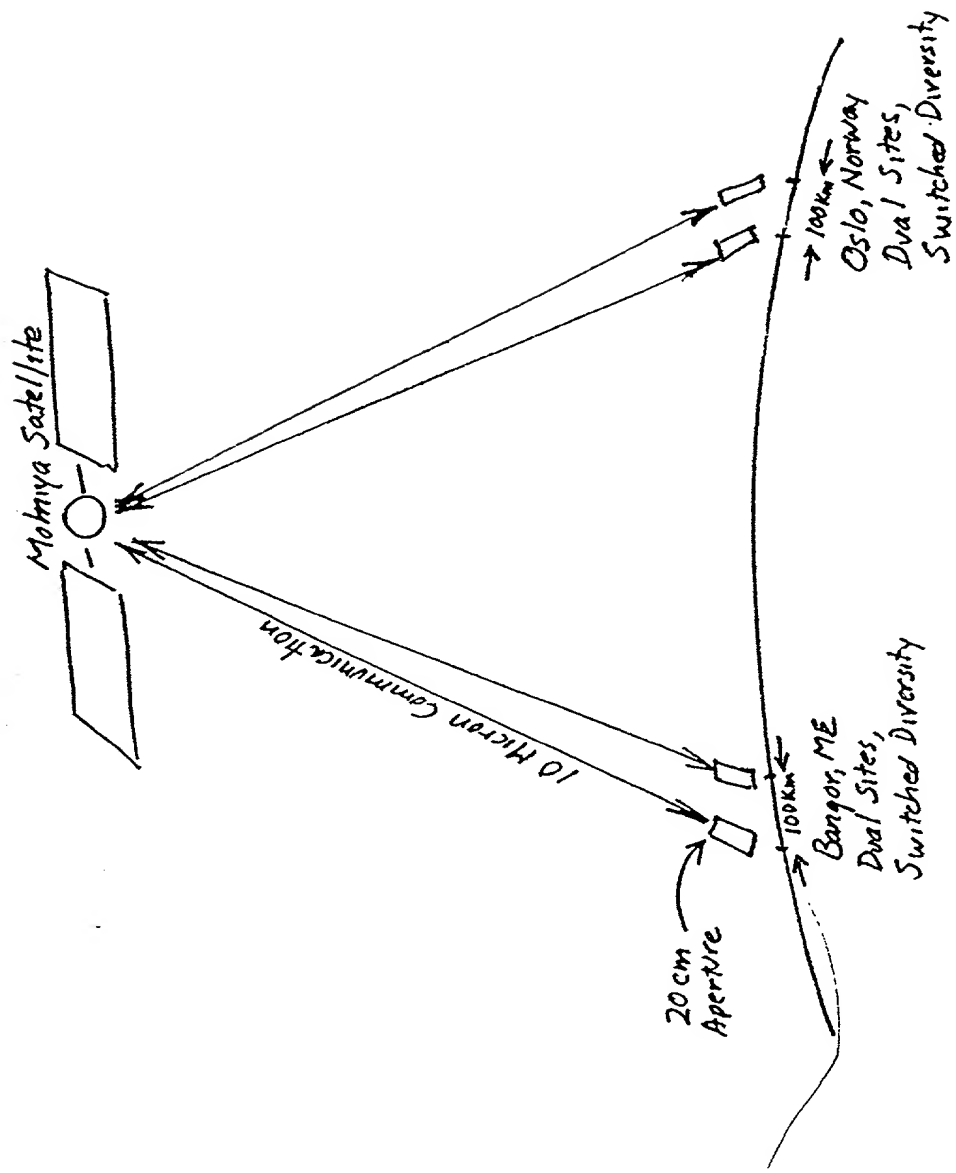
10 Micron Communication

20 cm Aperture

→ 100 km ←
Bangor, ME
Dual Sites,
Switched Diversity

→ 100 km ←
Oslo, Norway
Dual Sites,
Switched Diversity

Fig. 23

Molniya Satellites

10 micron Communication

Oslo, Norway

Bangor, ME
2 co-located sites
for Angle Diversity

Fig. 24